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CA00/1354

Specification and Drawings, as originally filed, with Application for Patent Serial No:
2,290,053, on November 18, 1999, by ZENON ENVIRONMENTAL INC., assignee of
Steven Pedersen and Pierre Côté, for "Immersed Membrane Module and Process".

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ABSTRACT

5 An element for use in ultrafiltration or microfiltration of potable
water has a large number of small diameter hollow fibre membranes
attached in a slightly slackened state between two headers but in fluid
communication with only one of the headers. Side plates attached to the
sides of the headers define vertical flow channels containing the
membranes. The headers, membranes, side panels and T connectors define
membrane elements which may be placed side by side with other elements
to create membrane modules which can be stacked on top of each other to
10 form membrane cassettes of various sizes having continuous vertical flow
channels through the entire cassette. To pot the fibres, a suitable number of
fibres are gathered in a bundle and dipped in a pool of liquid wax which
freezes seconds after the bundle of fibres are removed. The waxed fibre
bundle is then inserted into a recess in a header. Potting resin is poured
15 into the header to cover the fibre bundle to a depth greater than the distance
that the wax wicked up the fibres. The wax is melted out of the header. The
membrane modules or cassettes are arranged in an open tank to cover a
substantial part of the cross sectional area of the tank, preferably 80% or
more. In first and second processes, tank water flows upwards and
20 downwards through the flow channels respectively.

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Title: Immersed Membrane Module and Process**FIELD OF THE INVENTION**

This invention relates to an immersed module of hollow fibre filtering membranes and in particular to a module in which the membranes are oriented horizontally and used to filter water containing low concentrations of suspended solids, for example, to filter surface water to produce potable water. The invention further relates to the design and operation of a reactor which uses such modules as part of a process for filtering water containing low concentrations of suspended solids, for example, filtering surface water to produce potable water.

BACKGROUND OF THE INVENTION

Early membrane filtration technology focused on providing hollow fibre membranes in small cartridges or shells. Feed water was typically introduced into the shells at high pressure thus driving permeate through the membranes. The high pressure allows a small number of membranes to be used to achieve a desired rate of permeate production. The small volume of the shells and the presence of high pressure pumps in the system allows the membranes to be cleaned vigorously by flowing feed at high speed across the surface of the membranes and by high pressure backwashing.

While development of shelled systems continues, the inventors herein and others developed a shell-less module which they described in U.S. Patent No. 5,248,424 which issued on September 28, 1993 to

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Zenon Environmental Inc. In this module, hollow fibre membranes are held in fluid communication with a pair of horizontally spaced headers to form modules in a variety of configurations in which the fibres vary from being substantially horizontal to substantially vertical. The modules are
5 unconfined in a shell and immersed in a comparatively large open tank. In production, transmembrane pressure ("TMP") is provided by suction on the lumens of the fibres and typically ranges from about 50 kPa to 100 kPa. The membranes are cleaned in part by backwashing. In addition, however, the
10 influence of air bubbles provided from below the membranes. The rising air bubbles physically clean the membranes on contact and also create a circulation pattern in the tank water which removes solids rich water from the membrane module and replaces it with fresh feed water.

15 Subsequently, further shell-less membrane modules based in part on similar principles appeared with hollow fibre membranes in both substantially vertical and substantially horizontal orientations. Shell-less modules with membranes oriented vertically are shown in U.S. Patent No. 5,639,373 issued to Zenon Environmental Inc. on June 17, 1997; U.S. Patent
20 No. 5,783,083 issued to Zenon Environmental Inc. on July 21, 1998 and PCT Publication No. WO 98/28066 filed on December 18, 1997 by Memtec America Corporation. In these modules, the horizontally spaced headers are replaced by headers spaced vertically only and various alterations to the apparatus allow the membranes to move under the influence of scouring
25 air bubbles in the new configuration.

Shell-less modules with membranes oriented horizontally are described in U.S. Patent No. 5,480,553 issued to Mitsubishi Rayon Co., Ltd on January 2, 1996; Japanese Published Applications JP-07024272, JP-07178321, JP-07275665 and JP-09215980 filed on January 27, 1995, July 18,

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1995, October 24, 1995 and August 19, 1997 respectively by Mitsubishi Rayon Co., Ltd and in an article, "Development of a tank-submerged type membrane filtration system", by K. Suda et. al. of Ebara Corporation published in Desalination 119 (1998) 151-158.

5 Despite the proliferation of membrane module designs, membrane filtration technology has not achieved wide acceptance for use in creating potable water from a supply of surface water. In particular, despite the improved quality of water filtered through membranes, sand filters are still used more often, largely because of their much lower cost. For
10 example, the performance of a shell-less module with horizontal membranes was tested by Ebara Corporation and the results reported in the article mentioned above. While the authors were able to achieve stable operation over extended periods of time, the tank superficial velocity (the flux of permeate, typically in m^3/h , divided by the tank footprint, typically
15 in m^2) was only about 1.7 m/h. In comparison, a typical sand filtration system has a tank superficial velocity of 5 - 10 m/h allowing for the use of much smaller tanks - a significant cost in a large municipal or industrial system. Of the shell-less modules with vertical membranes, modules produced by Zenon Environmental Inc. have been installed and operated to
20 produce tank superficial velocities of over 10 m/h using strong membranes supported with a substrate and fairly intense aeration. Both the complex membranes and the intense aeration, however, increase the cost of such technology. Depending on the application, such intense aeration may also produce foam on the water surface which must be controlled by periodically
25 spraying to avoid cleanliness or safety problems. With either configuration, a large portion of the tank must remain open to provide space for tank water descending outside of the modules according to the circulation pattern created by the air bubbles.

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Aside from tank, membrane materials and aeration costs, the cost of manufacturing membrane modules remains a concern. In particular, potting a large number of fibres successfully is still problematic. For example, in many of the Mitsubishi references cited above the hollow
5 fibres are made into a knitted or woven fabric so that they may be inserted into a header. The header is then centrifuged to force potting resin into the spaces between fibres while inhibiting potting resin from wicking too far up the membranes. In Zenon's '373 patent mentioned above, a method is described in which centrifuging is not required but the method is best suited
10 to larger diameter fibres.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a hollow fibre membrane module adapted for use in filtering water as part of a
15 process of producing potable water. It is another object of the present invention to provide a process which uses immersed filtering membranes as part of a process of producing potable water.

In one aspect, the invention is directed at a membrane module having two opposed vertically extending headers. A large number
20 of small diameter hollow fibre membranes having no substrate are attached in a slightly slackened state between two rectangular solid headers but in fluid communication with only one of the headers which has a permeate conduit. The membranes are generally horizontal but slant slightly upwards towards the header with the permeate channel. Side plates
25 attached to the sides of the headers and extending between them protect and contain the membranes while defining vertical flow channels containing the membranes. The membranes have a packing density of about 15% to 25%. The header having the permeate channel is capped at its upper end

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with a T connector and has a recess at its lower end to admit a T connector from a header below it. The headers, membranes, side panels and T connectors define membrane elements which may be placed side by side with other elements units to create membrane modules which can be stacked on top of each other to form membrane cassettes of various sizes having continuous vertical flow channels through the entire cassette. In operation, permeate flux is between 10 and 50 L/m²/h. Aeration is provided in the absence of permeation directly before, directly after or during backwash at a superficial velocity (m³/h of air at standard conditions per m² of module cross-sectional area) of 80 m/h to 340 m/h and during permeation at 0.0 m/h to 80 m/h or intermittently.

In another aspect, the invention is directed at a method of manufacturing a membrane module as described above. Headers in the shape of a rectangular solid are moulded of a suitable plastic with an inner recess defining a permeate channel. A heater is placed in a lower portion of the recess and covered with solidified wax. A suitable number of fibres are gathered in a bundle without attempting to arrange the fibres in a grid or matrix. The bundle of fibres is dipped in a pool of liquid wax maintained at a temperature such that the wax freezes seconds after the bundle of fibres are removed to prevent excessive wicking. The wax seals the ends of the fibres, surrounds the fibres and holds them in a closely spaced apart relationship. The waxed fibre bundle is then inserted into the recess of the header. Potting resin is poured into the header to cover the fibre bundle to a depth greater than the distance that the wax wicked up the fibres. The electric heater is turned on to liquify the wax so that it flows out leaving a clear permeate channel in communication with the lumens of the membranes.

The membrane modules or cassettes are arranged in an

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open tank to cover a substantial part of the horizontal cross sectional area of the tank, preferably 80% or more. The upper perimeters of the modules or cassettes are surrounded by a casing to enclose a volume directly above the module. In one embodiment, the casing is provided with a retentate outlet
5 from the tank. Feed water is added to the tank to maintain a normal level of tank water above the retentate outlet. Thus, tank water is forced upwards through the vertical flow channels. Tank water that is not withdrawn as permeate flows out of the tank through the retentate outlets. The supply of feed is controlled to provide a selected flow out of the retentate outlet. In
10 another embodiment, the tank is provided with a retentate outlet and feed water is added to directly to the casing and tank water flows downwards through the vertical flow channels.

BRIEF DESCRIPTION OF THE DRAWINGS.

Preferred embodiments of the present invention will now
15 be described with reference to the following figures.

Figures 1A and 1B are elevation and plan views of a filtering element respectively.

Figure 1C is an isometric view of a portion of a filtering
20 element.

Figure 2 is an isometric view of a module made of the elements in Figures 1A, 1B and 1C.

Figure 3 is an isometric view of a sub-module aerator.

Figure 4A is an isometric view of a cassette made of the

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modules of Figure 2.

Figure 4B is an isometric view of an assembly of 6 of the cassettes of Figure 4A.

Figures 5A and 5B are representations of steps in the manufacture of the element of Figures 1A and 1B.

Figures 6 and 7 are schematic representations of filtering reactors.

DETAILED DESCRIPTION OF EMBODIMENTS

Referring now to Figures 1A and 1B, a filtering element 10 is shown in elevation and plan views respectively. The element 10 has a closed header 12 and an open header 14 held in horizontally spaced relationship by a side plate 16. Preferably, the closed header 12 and an open header 14 are rectangular solids (but for cavities etc.) and the side plate 16 is attached to the closed header 12 and open header 14 by snap fittings, screws or glue. A plurality of hollow fibre membranes 18 are attached between the closed header 12 and the open header 14, the lumens of the membranes 18 in fluid communication with one of two permeate channels 20 in the open header 14. The membranes 18 are held in a closely spaced apart relationship in a plug of potting resin 22 which encloses the permeate channels 20 of the open header 14. The resin 22 surrounds each membrane 18 so that water cannot enter the permeate channel 20 other than by passing through the walls of the membranes 18. The membranes 18 have a pore size in the microfiltration or ultrafiltration range, preferably between 0.003 and 10 microns and more preferably between 0.01 and 1.0 microns.

The membranes 18 may each be a distinct fibre having an open end and a closed end but preferably the membranes 18 are made of looped fibres

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having open ends 24 in fluid communication with a permeate channel 20 of the open header 14 and looped ends 26 connected to the closed header 12. The membranes 18 are unsupported internally (ie. by a substrate) or externally (ie. by transverse fibres) and can be made, for example, of cellulose acetate, polypropylene, polyethelene, polysulfone and preferably of a complex of PVDF and calcined .alpha.-alumina particles as described in U.S. Patent No. 5,914,039, incorporated by this reference. In order to produce a large surface area, the membranes 18 have small outside diameters in the range of 0.2 mm to 1.0 mm. With such small diameter membranes 18, head loss in the lumen of the membranes 18 is significant and preferred effective lengths of fibre are short - between 0.2 m for smaller diameter fibres to 1.0 m for larger fibres. The effective length is defined as the maximum distance between an un-potted point on the membranes 18 and the proximal face of the open header 14 and, accordingly, each loop of a membrane 18 is approximately twice the effective length plus length required for potting. With membranes 18 as described above, the tensile strength of the membranes 18 is low and the forces applied to the membranes 18 by aeration are a concern. By arranging the membranes 18 as loops with their looped ends 26 secured in the closed header 12, the unsupported length of the membranes, and thus the maximum forces on the membranes 18 from aeration, are reduced in half compared to the usual configuration wherein horizontal membranes are suspended between two permeating headers. The membranes 18 do not need to be sealingly secured to the closed header 12 but are fixedly attached so that tensile forces in the membranes 18 are transferred to the closed header 12. As an example, membranes 18 made of complex of PVDF and calcined .alpha.-alumina particles, as mentioned above, with an outside diameter of 0.6 mm and an inside diameter of 0.35 mm are suitable for an element 10 in which the proximal faces of the closed header 12 and the open header 14 are spaced between 610 and 615 mm apart. The length of the membranes 18, however, is slightly longer than the

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distance between the proximal faces of the closed header 12 and the open header 14 as will be explained below.

5 The membranes 18 are mounted so as to have between 0.1% and 5% slack and so as to be slanted slightly upwards towards the open header at about 5 degrees as measured along a line from their looped ends 26 to their open ends 24. The slackness of the membranes 18 allows them to vibrate under the influence of scouring bubbles which aids in inhibiting their fouling. The angle of the membranes 18 assists in withdrawing air from the looped ends 26 of the membranes 18 when a new module is first used after
10 manufacture or some maintenance procedures. Combining the slackness of the membranes 18 and their upwards angle may result in the membranes 18 sloping downwardly near their open ends 24, but air in the lumens of this part of the membranes 18 generally leaves the membranes 18 shortly after a transmembrane force is applied to the membranes 18.

15 The open header 14 and closed header 12 are injection moulded from a suitable plastic such as PE, PP, polyester or polycarbonate. The open header 14 is less than 1 m in length which is more convenient for injection moulding and allows various numbers of elements 10 to be stacked on top of each other to fill tanks of varying depths. The closed header 12 is shorter
20 by the length of a recess 28 sized to fit a permeate fitting 30 of a lower element 10. The open header 14 preferably has two permeate channels 20 each between 30 mm and 40 mm wide which provides a manageable size for the potting method which will be described below. Each bundle of membranes 18 is between 20 and 30 mm wide which allows water and
25 aeration to penetrate the bundle. For example, an element 10 having a closed header 12 that is 700 mm long, an open header 14 that is 100 mm wide and having two permeate channels about 35 mm wide and about 600 mm long can be built with approximately 31 000 membranes 18 of 0.6 mm

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outside diameter in two bundles about 25 mm wide for a total surface area of approximately 36 m². At a flux of 30 L/m²/h for example, the membrane module 10 would produce about 1.1 m³/h of permeate.

5 The permeate fitting 30 is connected to the permeate channels 20 by a permeate opening 32 at the top of the open header 14. The permeate fitting 30 is a rectangular solid (but for cavities etc.) having width similar to and depth similar or greater than the open header 14 so as to cover the top end of the open header 14. The permeate fitting 30 may be attached to the open header 14 by a removable water-tight fitting but is preferably glued or
10 ultrasonically welded to the open header 14. The permeate fitting 30 has a permeate cavity 34 within it connecting the permeate channel 20 with a side opening 36 on either side of the permeate fitting 30.

Referring to Figures 1A, 1B, 1C and 2, a plurality of elements 10 are
15 attached side by side to create a module 50. The width of the module 50 can be any convenient multiple, typically six to twelve, of the width of the elements 10. Preferably, the multiple is chosen to maximize the number of elements 10 that can be placed in a tank of a given size.

20 The permeate cavities 34 of adjacent permeate fittings 30 provide a continuous permeate header 52. Adjacent permeate cavities 34 can be attached to each other by gluing or ultrasonically welding them to produce a watertight assembly. In this case, the width of the permeate fittings 30 needs to account for the side plates 16. As shown in Figure 1C, area for gluing or ultrasonic welding is increased with a ring 37 and corresponding recess 39. Alternately, and preferably if disassembly is anticipated, a male part 38
25 having a sealing member 40, typically a rubber O-ring, can be inserted into a mating side opening 36 of an adjacent element 10 as shown in Figures 1A and 1B. A permeate fitting 55 to collect permeate as required can be attached

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to both ends of the permeate header 52 but is more typically attached to only one side, the other side being sealed with a cap 54. Referring to Figures 1C and 2, knobs 41 and corresponding indents 43 help align modules 50 when stacked on top of each other as will be described below.

5 Referring to Figure 2, when the elements 10 are attached side-by-side, the side plates 16 of adjacent elements 10 define vertical flow channels 56 containing the membranes 18. The last element 10 has an additional side plate 16 to define a flow channel 56 in it. The width of the flow channels 56 is such that the membranes 18 move sideways enough to substantially fill a
10 central portion of the flow channels 56, the central portion preferably being between a third and two thirds of the distance between the proximal faces of the open header 14 and closed header 12. The reduced length of the membranes 18, compared to a design in which permeate is withdrawn from both ends of the membranes 18, tends to reduce tangling of the membranes
15 18 and reduces the width of the flow channel 16 allowing more compact elements 10. The side plates 16 also protect the membranes 18 from damage during shipping, installation or maintenance and temporary side plates 16 are used as necessary when elements 10 or sections of modules 50 are handled.

20 Referring now to Figure 3, a sub-module aerator 60 is shown having a header 62 connected to a series of parallel conduit aerators 64 having holes 66 to produce scouring air bubbles. The spacing between the conduit aerators 64 is preferably the same as the width of the elements 10. Alternately, the conduit aerators 64 can be placed perpendicular to the
25 elements 10 and the holes 66 spaced apart by the width of the elements 10. In this way, the sub-module aerator 60 can be installed to provide a source of air bubbles directly below the flow channel 56 of each element 10. Such an arrangement promotes a controlled amount of aeration being provided

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to each element 10 and minimizes air flow channelling which can starve membranes 10 of air, particularly when aeration rates are low. If required, a conduit aerator 64, or a hole 66 in a conduit aerator 64 perpendicular to the elements 10, can be provided directly below the side plate 16 between each pair of elements 10 to similar effect, although the first arrangement described is preferred.

Referring to Figure 4A, a cassette 80 has three modules 50 stacked on top of each other such that their flow channels 56 align. Cassettes 80 can also be made with various other numbers and arrangements of modules 50. The modules 50 are held together in a sub-frame 82. Referring to Figure 4B, groups of three cassettes 80 are made into an assembly 84 by connecting their sub-frames 82 to produce a full frame 86. Assemblies 84 can be made with various other numbers and arrangements of cassettes. The cassettes 80 are each provided with a bar 88 and hook 90 to facilitate installation and removal of an assembly 84. Pairs of assemblies 84 are preferably installed with their associated permeate fittings 55 occupying a common central space 92. The permeate fittings 55 from each cassette 80 are connected to form permeate collectors 94 extending upwards through the central space 92.

Referring to Figures 4A and 4B, a casing 96 is fitted over the top of a cassette 80 or assembly 84 to provide a volume above and in fluid communication with the flow channels 56. Alternately, as shown in Figures 6 and 7, a casing 96 is fitted over a plurality of assemblies 84 to provide a common volume above them and the central spaces 92 are separated from the volume by plates 98 fitted around the permeate fittings 55 or permeate collectors 94 as required to prevent significant amounts of water from flowing into the central space 92 when the casing 96 is full of water.

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Referring now to Figures 6 and 7, assemblies 84 rest on stands 98 on the floor of a tank 100. Preferably, the assemblies 84 are sized and positioned to fill as much of the tank 100 as is practicable leaving room for necessary fittings and other apparatus and maintenance or set-up procedures but not for downcomers. Preferably, 80% or more of the horizontal cross-sectional area of the tank 100 is filled with assemblies 84. Such assemblies 84 can provide 700-800 m² of surface area of membranes 18 for each m² of footprint or horizontal cross-sectional area of tank 100 resulting in a superficial tank velocity at a flux of 30 L/m²/h of over 20 m/h.

Referring still to Figures 6 and 7, the stands 98 support sub-module aerators 60 in position relative to the flow channels 56 as described above. The headers 62 of the sub-module aerators 60 are connected to air supply pipes 102 in turn connected to an air supply 104. The permeate collectors 94 are connected to a permeate header 106 in turn connected to a permeate pump 108 and permeate outlet 110 with permeate valves 112. To facilitate backwashing, a permeate storage valve 114 is opened from time to time to fill a permeate storage tank 116. Stored permeate can then be used to backwash the assemblies 84 by closing permeate valves 112 and opening a pair of backwashing valves 120 in a backwash line 118. Permeate pump 108 is then operated to flow permeate from the permeate storage tank 116 in a reverse direction through permeate collectors 94 and the assemblies 84.

Referring now to Figure 6, the casing 96 is provided with an outlet 120 connected to a drain 122. Feed water 124 is drawn from a feed supply 126 by a feed pump 128 and enters the tank 100 through an inlet 130 between the perimeter of the casing 96 and the wall of the tank 100. Feed water 124 enters the tank, wherein it will be called tank water 132, flows downward around the casing 96 and assemblies 84 to the bottom of the tank 100 and upwards through the flow channels 56. Tank water 132 which is not

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removed as permeate continues to flow upwards to the volume of the casing 96 from which it leaves the tank 100 through the outlet 120.

Referring to Figure 7 an alternate arrangement is shown. A second tank 200 is provided with an outlet 120 connected to a drain 122. Feed water 124 enters the second tank 200 through a second inlet 230 inside or directly above a second casing 196. Feed water 124 enters the second tank 200, wherein it will be called tank water 132, flows downward through the flow channels 56. Tank water 132 which is not removed as permeate reaches the bottom of the second tank 200 and flows upwards past the assemblies 84 and second casing 196 and leaves the second tank 200 through the outlet 120.

In both Figures 6 and 7, the tank water 132 flowing in the flow channels 56 has a significant effect in preventing a build-up of solids in the assemblies 84 and thus substantially replaces the need for aeration to circulate tank water 132. Aeration is still provided, however, to scour the membranes 18 which is accomplished even when bubbles rise counter to a flow of tank water 132. Further, if permeate flux is kept below about 35 L/m²/h, the inventors have found that surprising little fouling occurs and gentler aeration is sufficient. More surprisingly, the energy cost savings produced by operating at low flux and low aeration more than offsets the cost of providing a large membrane surface area in the form of the elements 10 and modules 50 described above. The inventors believe that the horizontal orientation of the membranes 18, providing a source of air bubbles directly below one or two flow channels 56, the distribution of membranes 18 in the flow channels 56 and the flow of tank water 132 through the flow channels 56 assists in reducing the amount of aeration required. If foam is still produced by the limited aeration, the outlet 120 is preferably a weir which allows the foam to flow out of the tank 100 or second tank 200.

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Preferably, the most strenuous aeration is provided during a period when permeation is stopped directly before, directly after or during a backwash. At this time, the aeration does not need to overcome suction on the membranes 18 to dislodge solids from the membranes 18 and aeration is provided at a superficial velocity (m^3/h of air at standard conditions per m^2 of module cross-sectional area) between 80 m/h and 340 m/h . Such aeration inhibits fouling of the membranes 18. Aeration may also be provided at other times at the same rate for feed water containing solids which foul the membranes 18 rapidly. For many if not most feed waters, however, aeration to inhibit fouling is not required at other times. Such feed waters typically have low turbidity and solids concentrations less than about 500 mg/L . For filtering these feed waters, a smaller amount of aeration is advantageously provided during permeation to disperse solids form dead zones in a cassette 80. For this purpose, aeration is provided at a superficial velocity between 0.0 m/h to 80 m/h or intermittently at the higher rates described above.

Referring still to Figures 6 and 7, a process may be operated with tank water 120 substantially continually flowing out of the outlet 120, feed water 124 substantially continually entering the tank 100 or second tank 200 and permeate substantially continuously withdrawn from the tank 100 or second tank 200. The amount of permeate leaving the tank 100 or second tank 200 as a percentage of the feed water 124 entering the tank 100 or second tank 200 is referred to as a recovery rate and is preferably 90% or more and more preferably 95% or more when the tank water 132 leaving the tank 100 or second tank 200 will not be filtered further. Based on a selected permeate flux and recovery rate, the required flow of feed water 124 can be calculated. The feed pump 128 is then operated by a controller 142 to deliver the required flow. Alternatively, if a gravity feed is desired, feed

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pump 128 can be replaced by a valve similarly controlled. Outlet 120 is preferably a V-shaped weir or large pipe with sufficient capacity to release the desired amount of tank water 132 without requiring extensive free board of the casing 96 or second tank 200.

5 The use of a V-shaped weir as an outlet 120 is preferred. Such an outlet compensates well for periodic increases in flow of tank water 132 out of the tank created by backwashing. Preferably, a level sensor 140 is provided in the casing 96 or second tank 200 to sense the level of the tank water 132 in direct fluid communication with the outlet 120. The level
10 sensor 140 communicates with the controller 142 which preferably incorporates a PLC.

 In a first mode of operation, when the level sensor 142 senses that the level of tank water 132 has risen over a selected value, the controller 142 stops the input of feed water 124 which is not restored until the level of the
15 tank water 132 returns to the selected value. The selected value is chosen to reflect the increase in the level of tank water 132 during a backwash event and has the effect of stopping feed during the backwash and for a period after the backwash required to as discharge the backwash water. Thus the level of the tank water 132 is moderated further reducing the need for free
20 board around the outlet and reducing the require capacity of the drain 122.

 In a second mode of operation, the amount of backwash water (being permeate) exceeds the flow of tank water 132 out of the tank 100 or second tank 200 required for a desired recovery rate. In this case, based on the level of the tank water 132 as communicated by the sensor 140, the controller 142
25 stops or slows the flow of feed in advance of a backwash as required to reduce the level of the tank water 132 to a selected value before the backwash, confirmed by the sensor 140. In this case, the selected value is

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below the outlet 120 as required to ensure that only a required portion of the backwash water exits the tank 100 or second tank 200. In a third mode of operation, this technique of stopping or slowing feed in advance of a backwash is used in conjunction with the first mode of operation above to further moderate fluctuations in the level of the tank water 132. To the extent that these operations create some transience in the flow of tank water 132 through the cassettes 80, such transience is beneficial in reducing dead zones and agitating the membranes 18 provided that the strength of the membranes is not exceeded.

Now referring to Figures 5A and 5B, first and second procedures are shown which are used together to potting an element 10. In the first procedure, membranes 28 in sufficient number to produce a potting density of 15 - 25 % (based on the cross-sectional area of the resin 22 normal to the membranes 28) are arranged in a bundle 130 and loosely held by a releasable collar 132. The bundle 130 is produced by winding fibre material on a drum but without purposely arranging the membranes 28 in a grid or matrix. The bundle 130 is dipped quickly in a pool of liquid wax 134, preferably polyethelene glycol such as Carbowax 1400 (a trade mark) produced by Union Carbide, maintained at a temperature slightly above its freezing point. The wax 134 wets the membranes 28 and moves upwards along the membranes 28 by capillary action. Because the temperature of the wax 134 is only slightly above its freezing point, however, the wax 134 freezes within seconds of when the membranes 28 were dipped into it. Thus, the height to which the wax 134 can travel is limited to about 5 to 10 mm. A plug 136 of wax 134 remains at the end of the membranes 28 which seals their ends and holds them in a closely spaced apart relationship. Since this operation is done in the open, the integrity of the plug 136 can be monitored visually.

Referring to the right half of Figure 5B, in the second procedure an

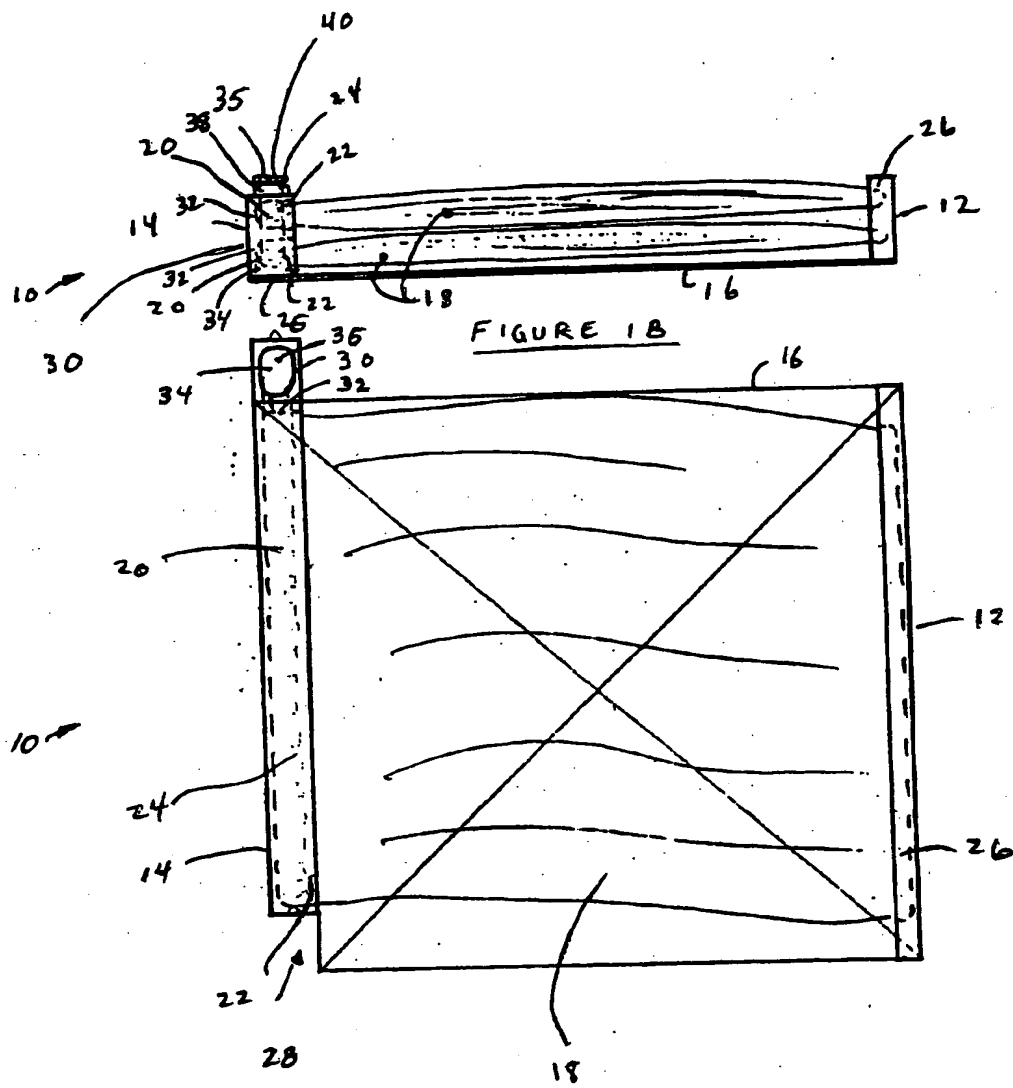
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open header 14 is placed with its permeate channels 20 facing upwards. A heater 138 is placed in the permeate channel 20 and covered in wax 134 which is allowed to freeze around it. The heater 138 is electric with wires to a power supply leaving the open header 14 through a permeate opening 32 which is sealed with a temporary end plate (not shown). The bundle 130 is placed in the permeate channel 20, the plug 136 ensuring that all membranes 28 enter the permeate channel 20. The permeate channel 20 is then covered with resin 22 to a depth of 20 to 60 mm above the top of the plug 136. The resin 22 is preferably polyurethane which will wet small diameter membranes 28 by capillary action. Other suitable resins include epoxy, rubberized epoxy and silicone rubber. One or more resins may be applied in one or more coats to meet different objectives of strength, compatability with the wax 134 and providing a soft interface with the membranes 28 having no cutting edges. After the resin 22 cures, the temporary end plate is removed and the heater 138 is turned on to melt the wax 134 which flows out of the permeate opening 32. The heater 138 is also removed through the permeate opening 32 leaving a clear permeate channel 20 in communication with the lumens of the membranes 28. The collar 132 is removed. A potted bundle 130 is shown in cross section on the left side of Figure 5B.

It is to be understood that what has been described are preferred embodiments of the invention. The invention nonetheless is susceptible to certain changes and alternative embodiments without departing from the subject invention, the scope of which is defined in the following claims.

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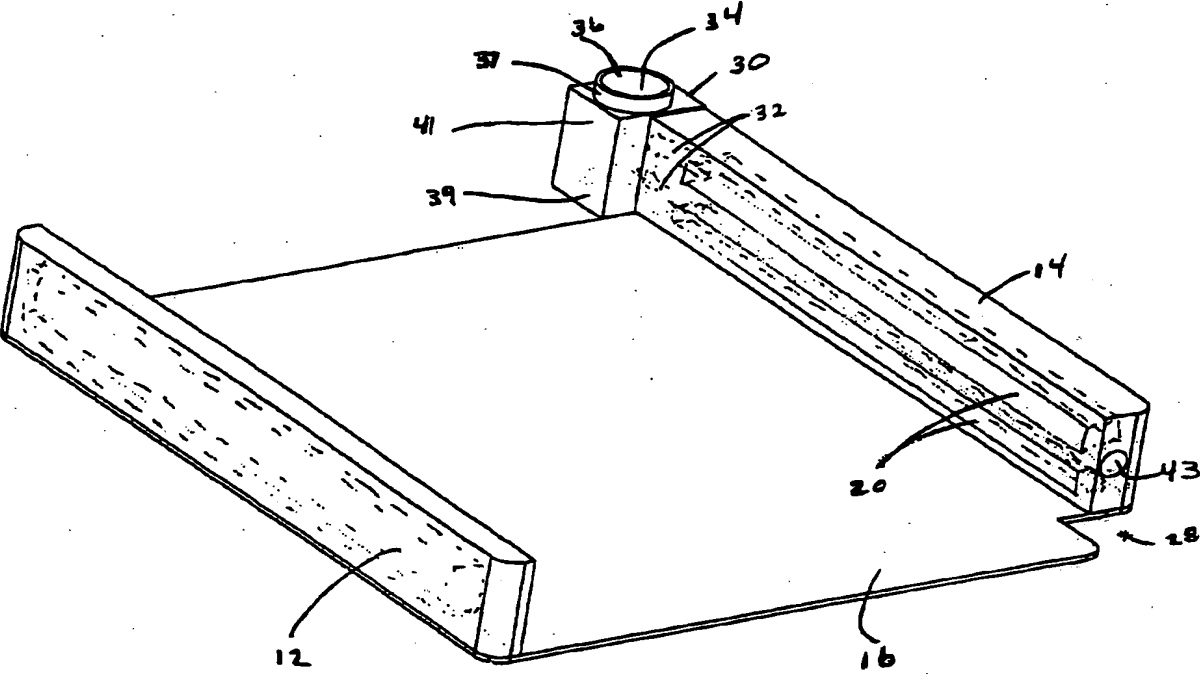


FIGURE 1C

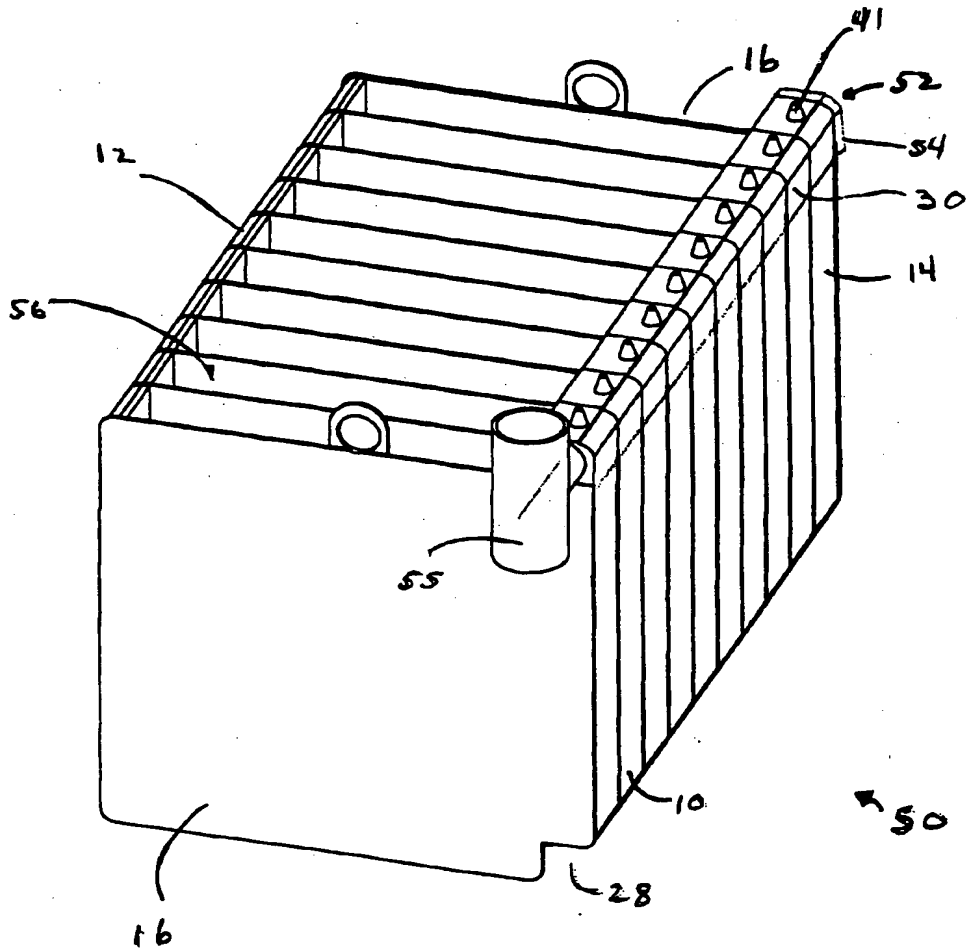


FIGURE 2

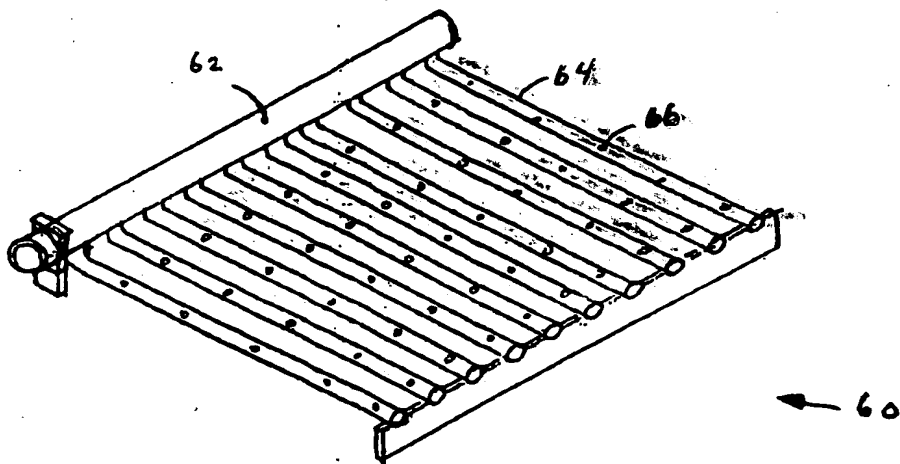


FIGURE 3

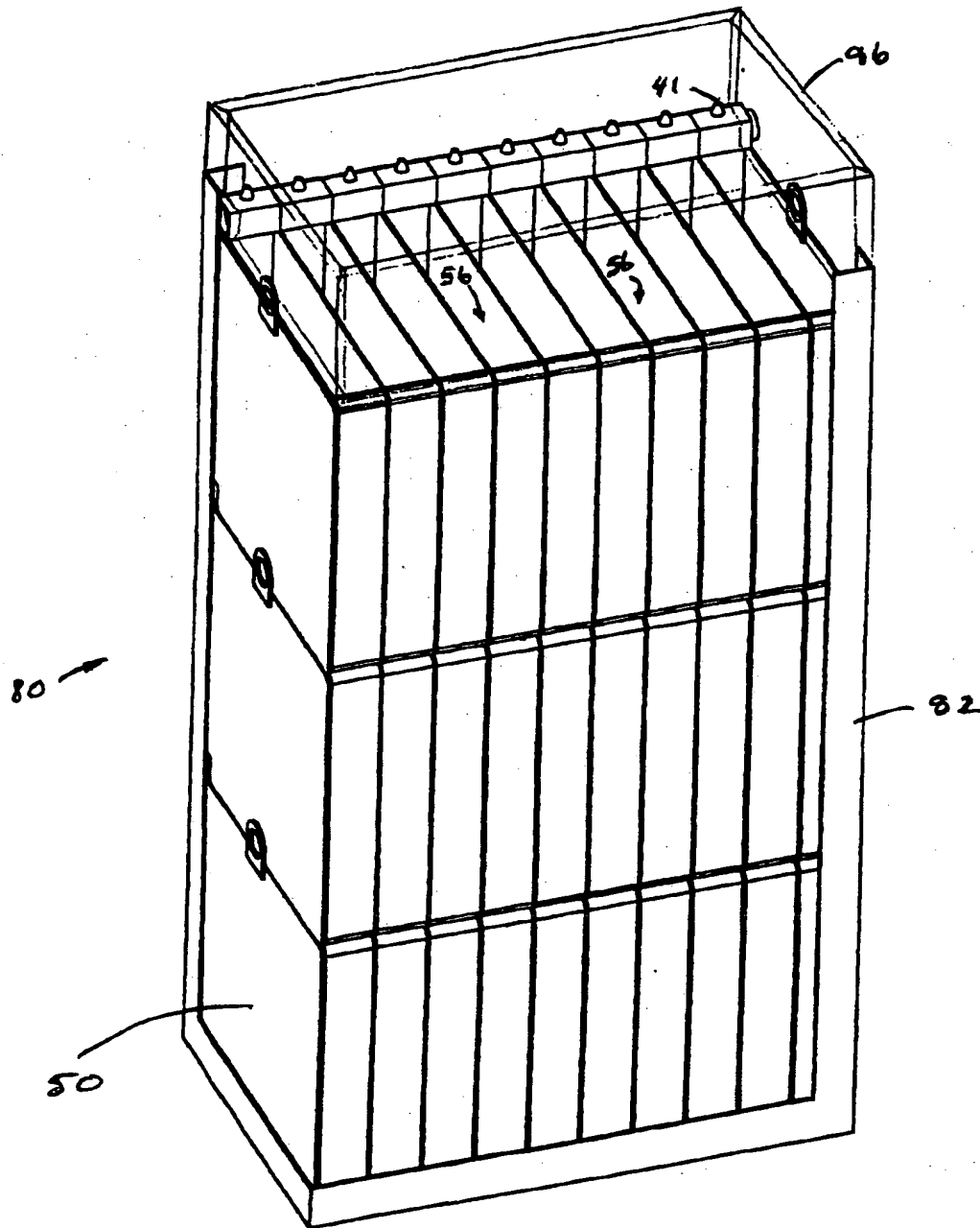
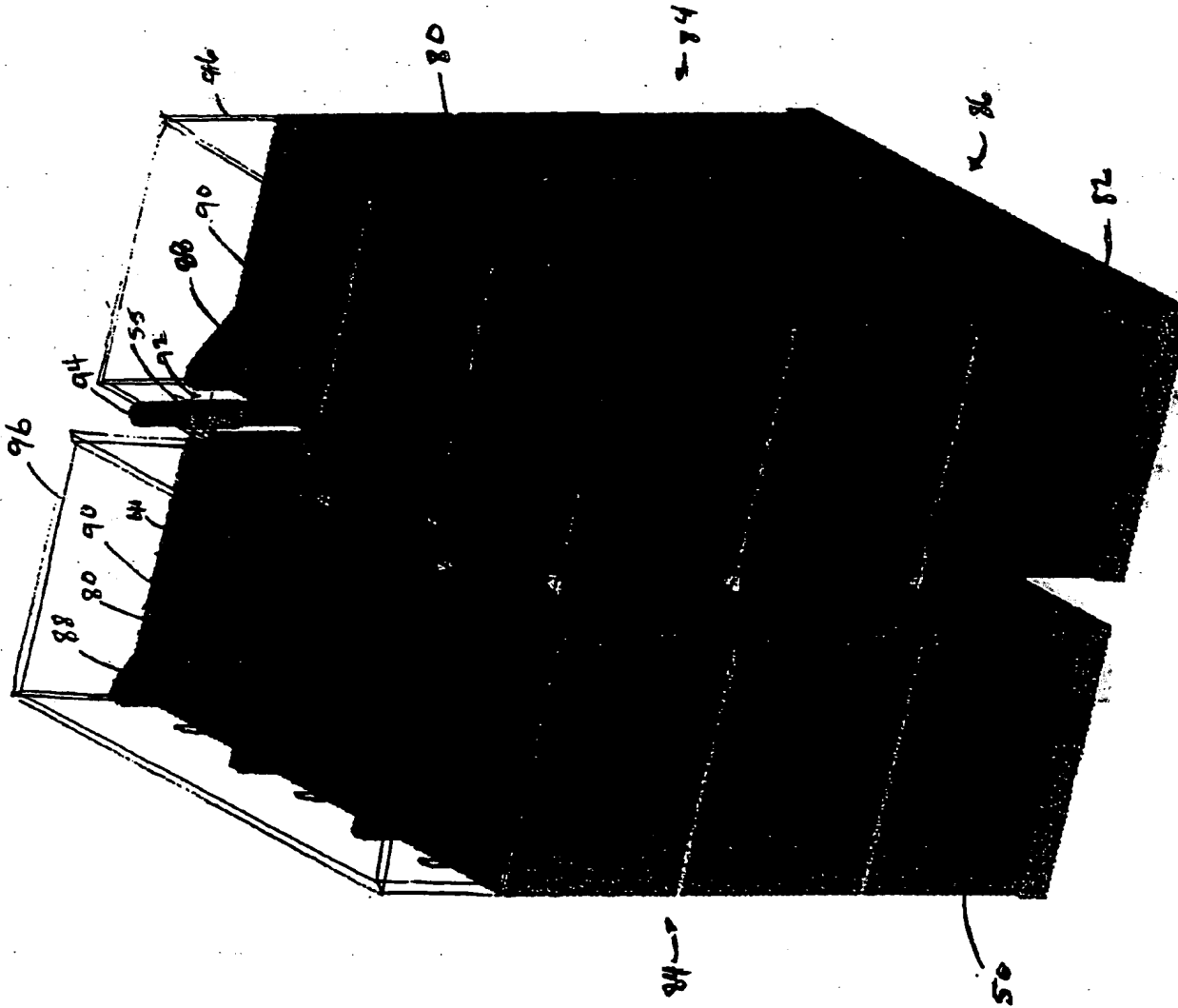


FIGURE 4A

FIGURE 4B



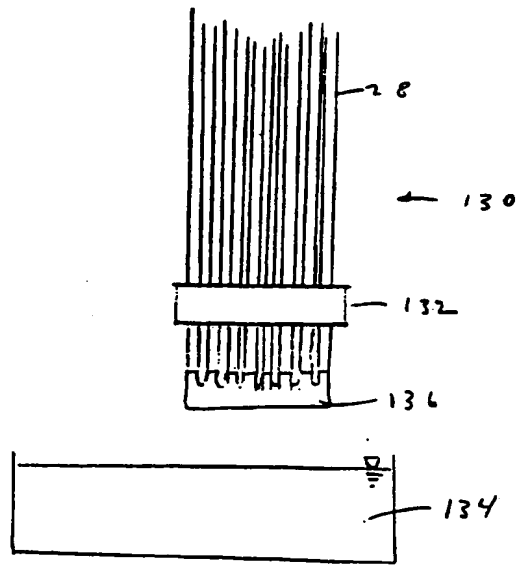


FIGURE 5A

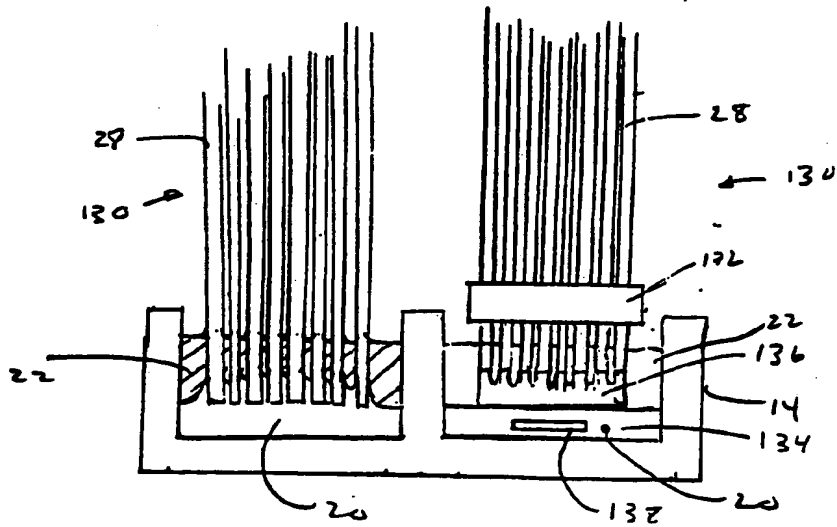


FIGURE 5B

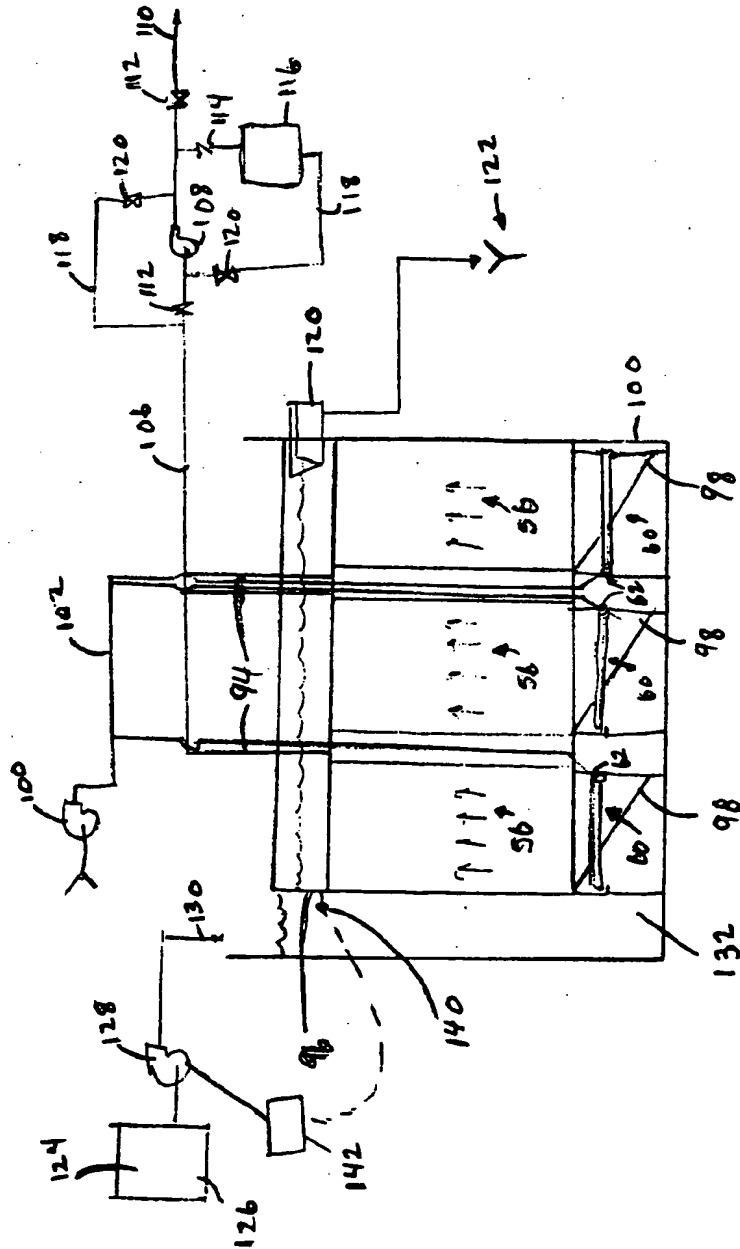


FIGURE 6

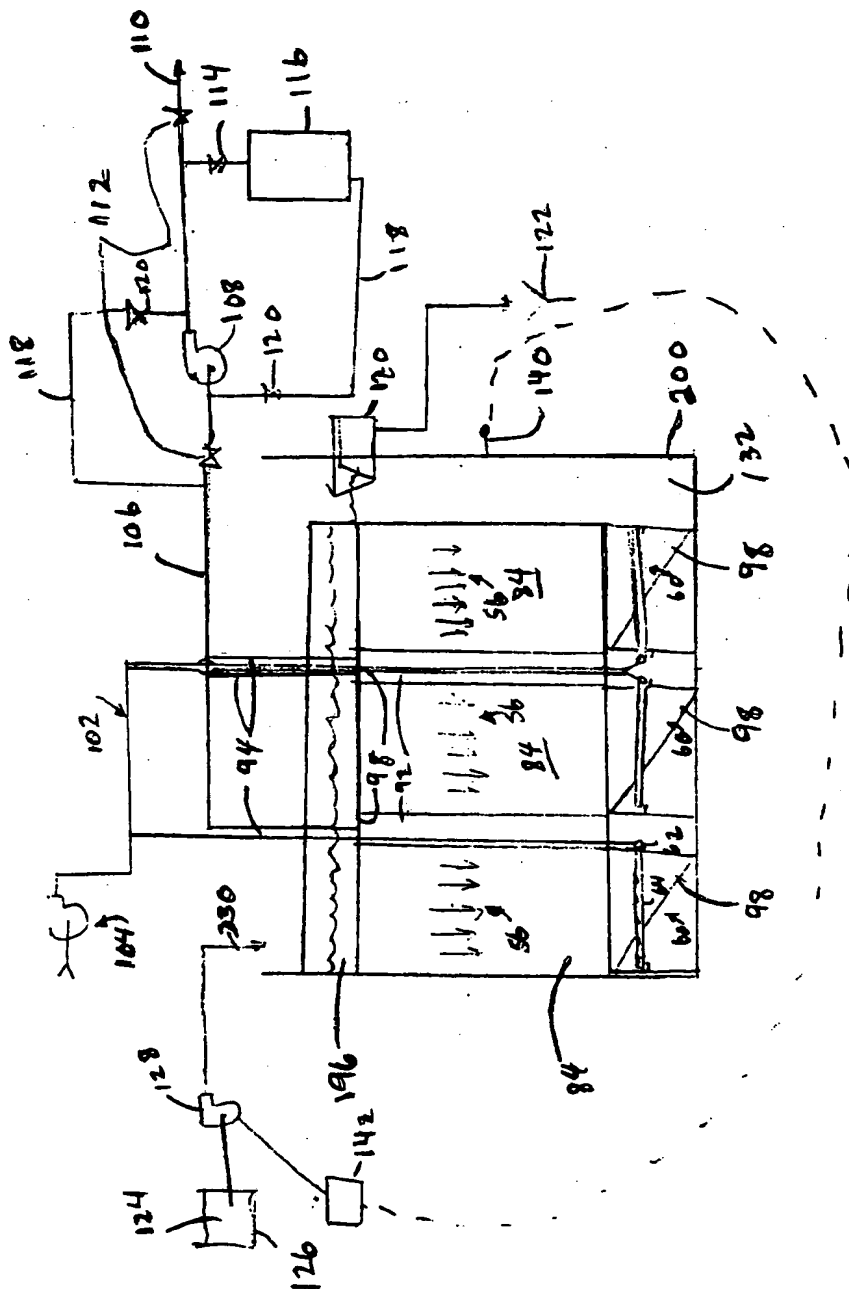


FIGURE 7

